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Title: 3D High Explosives Acoustic Temperature (3DHEAT) and Mechanical Damage

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3D High Explosives Acoustic Temperature (3DHEAT) and Mechanical Damage

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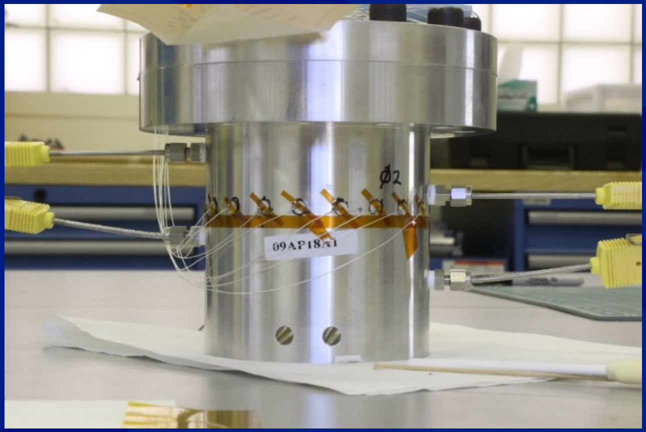
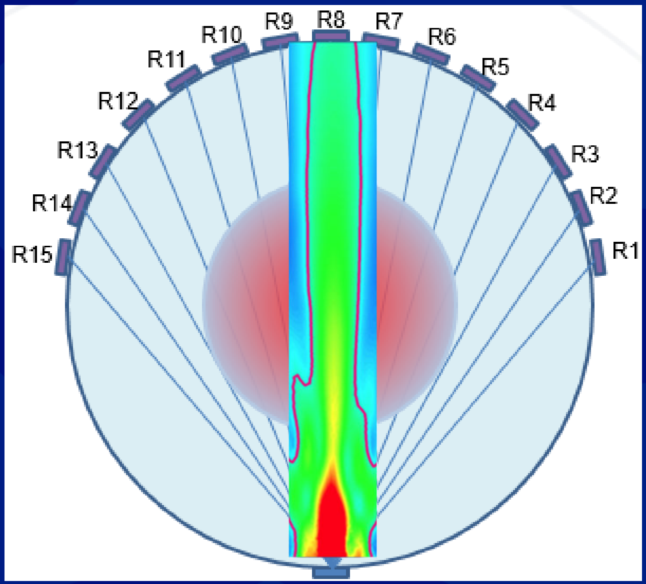
NSARD 2021
23 Apr 2021





3D High Explosives Acoustic Temperature (3DHEAT) and Mechanical Damage

Structure:

- **List of participating laboratories:**

  LANL

- **List of sub-contract organizations:**

  N/A

- **PIs and Co-investigators:**

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3DHEAT

Project overview/goals:

- Targeting explosive ***condition*** inside an unknown item.

- Both ***thermal*** and ***mechanical*** conditions are of interest, especially if the explosive is damaged.

- Outcomes:
  - Thermal: assess the time that remains before thermal damage ignites the explosive,
  - Mechanical: damage to the explosive may affect its performance

  How the explosive responds to various emergency response actions.

- Assessing the explosives condition from outside the casing in any phase remains challenging.
  - Low energy radiography does not provide sufficient penetration nor density contrast to assess mechanical damage, or thermal damage such as a melt-zone.
  - High energy radiography provides high penetration, but also tends to wash out finer contrasting features such as fractures and small density differences between solid and molten explosives.
  - Radiographic techniques in general do not provide sufficient quantitative information related to temperature.

3DHEAT

Technical approach:

- In order to assess thermal (e.g. temperature or phase) and mechanical damage (e.g. fractures or rubbleization), a combination of linear and nonlinear acoustics techniques will be used.

- A unique collimated low-frequency sound beam and beam scanning (linear acoustics), developed recently in our Acoustic Team, will be investigated for thermal damage, which can lead to spatially resolved 3D temperature field inside the sample.

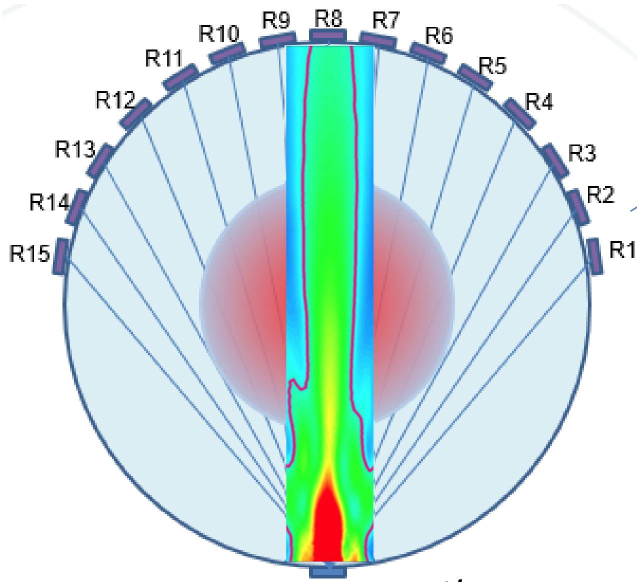
- Nonlinear acoustics approaches are more suitable for cracks and voids detection. Either higher harmonics, or difference frequency will be monitored for mechanical damage mapping.

3DHEAT

Technical approach:

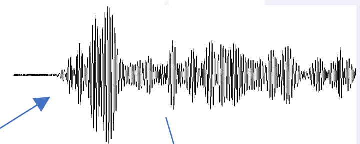
Linear Acoustics ~ Temperature

Knowledge of the explosive temperature field inside an unknown item can help to inform an assessment of the time that remains before thermal damage ignites the explosive, or how the explosive responds to various emergency response actions.



low-frequency collimated beam

Waveforms



Sound speed Determination

$$c = \frac{Diameter}{travel\ time}$$

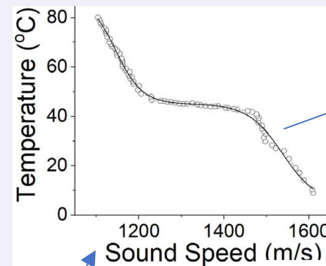
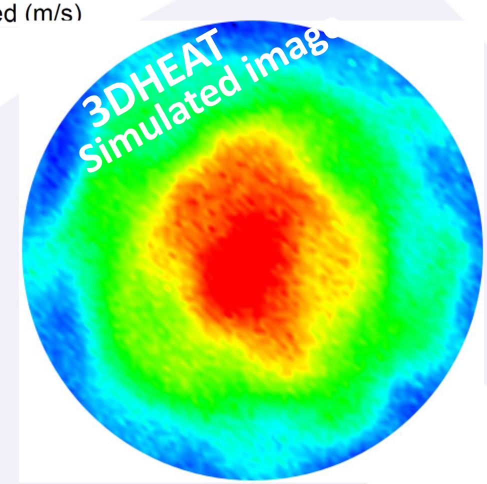
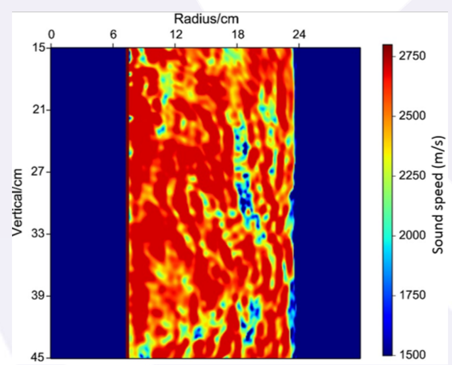


Image Reconstruction

Least-squares reverse-time migration/full-waveform inversion





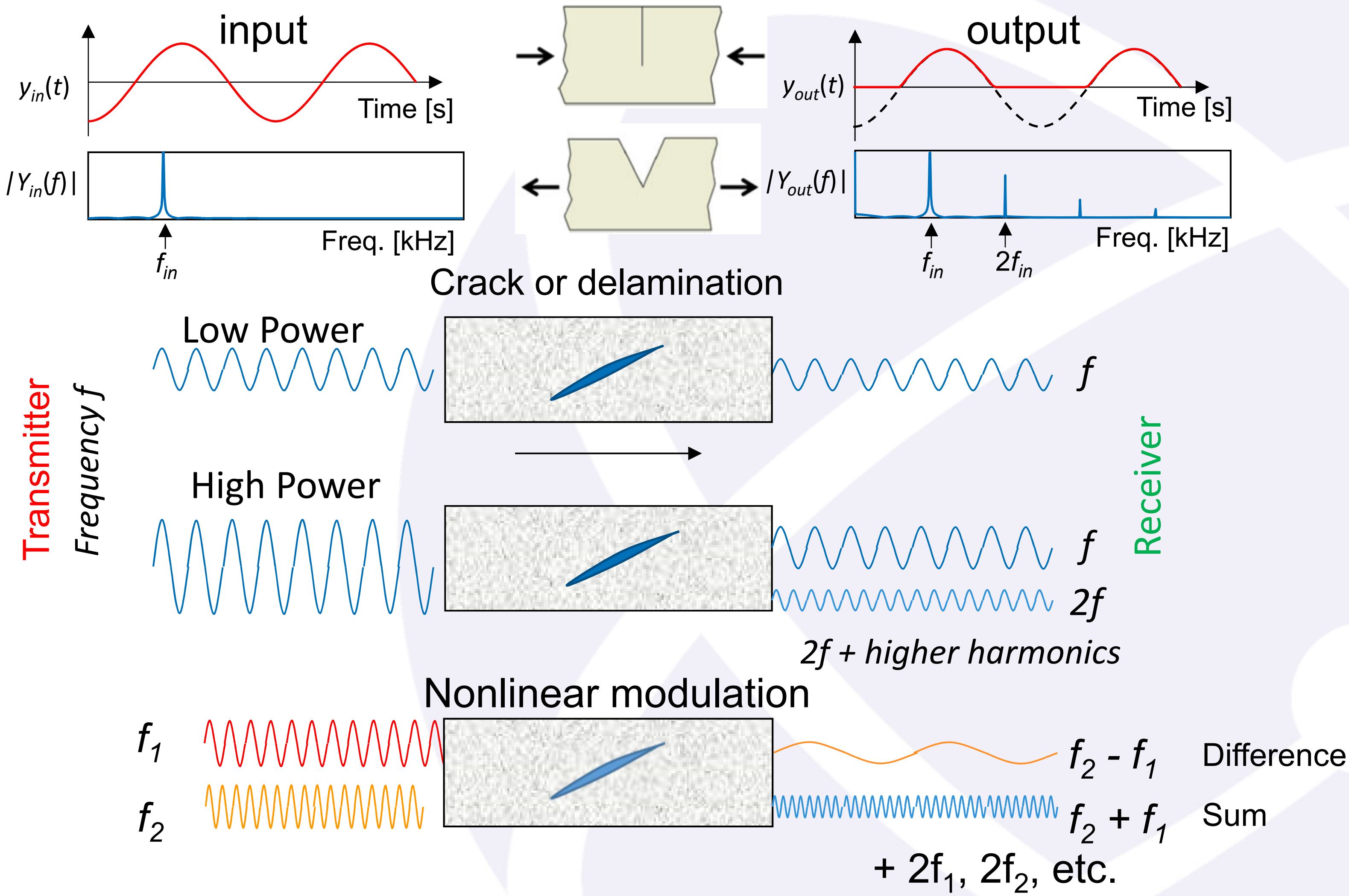
Two-dimensional sound speed gradient in a concrete block

3DHEAT

Technical approach:

Nonlinear Acoustics ~ Mechanical Damage

Contact acoustic nonlinearity: Cracks open/close resulting in nonlinearities



3DHEAT

Deliverables:

Title (as will be entered in webPMIS)	Description (as will be entered in webPMIS)	Associated Task(s)	Due Date
WebPMIS Budget Update	At a minimum, WebPMIS should be updated monthly to accurately reflect costing against the project	All	NLT the 10th for the previous month
Acoustics diagnosis of thermal damage in Pentolite	Technical report on acoustics capabilities for thermal damage detection in Pentolite	F	End of Y3/Q4
Acoustics diagnosis of mechanical damage in Pentolite	Technical report on acoustics capabilities for mechanical damage detection in Pentolite	J	End of Y3/Q4
Quarterly Report & WebPMIS Administrative Update	Per HQ format (uploaded and approved in WebPMIS)	All	w/in 10 days EOQ
Annual TRL Readiness Assessment	Per HQ format	All	w/in 30 days EOY
Final Report	Per HQ format	All	w/in 30 days EOP

3DHEAT

Description of capability improvement to be addressed by project success (relevant to the non-proliferation mission):

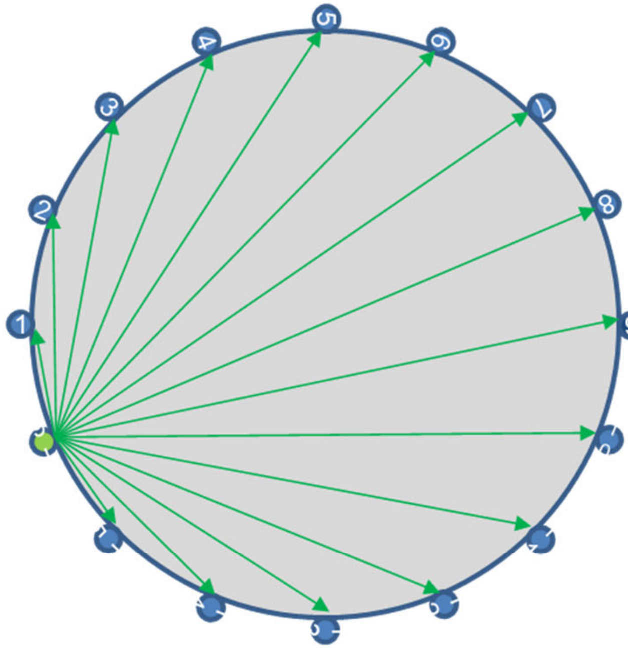
If successful, this deployed technology will greatly enhance the emergency response community's ability to *move left*.

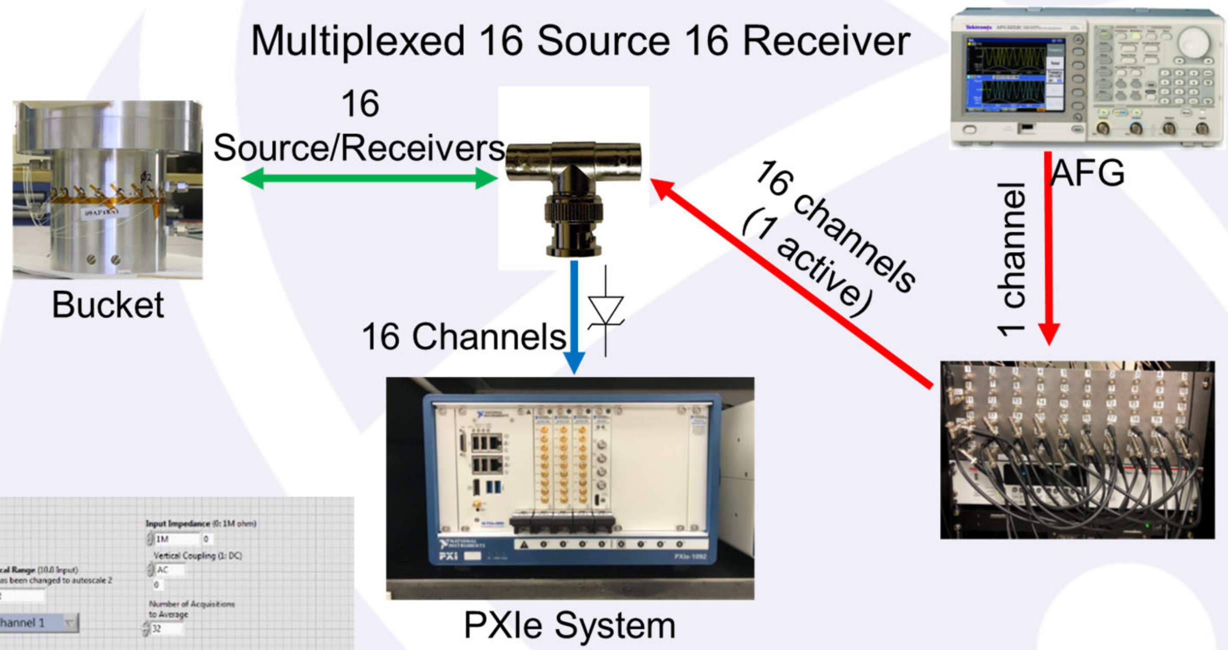
Moving left means decisions to mitigate risk can be made at earlier times during the response operation, and with reduced uncertainty.

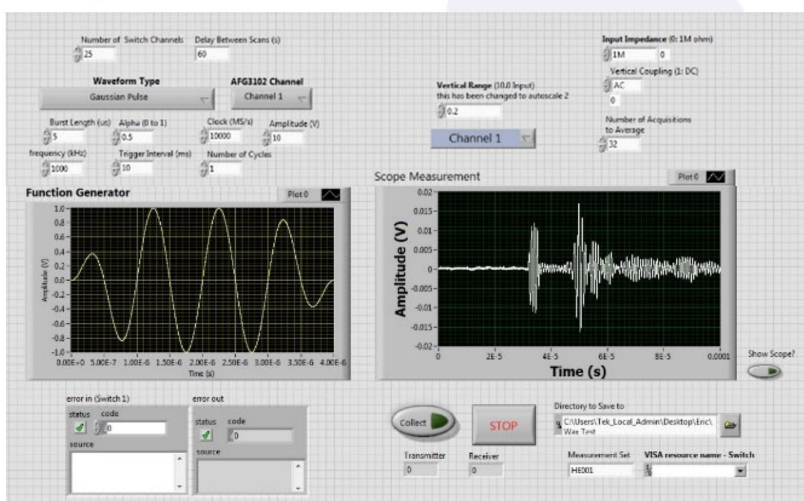
3DHEAT

Progress to date:

Instrumentation development



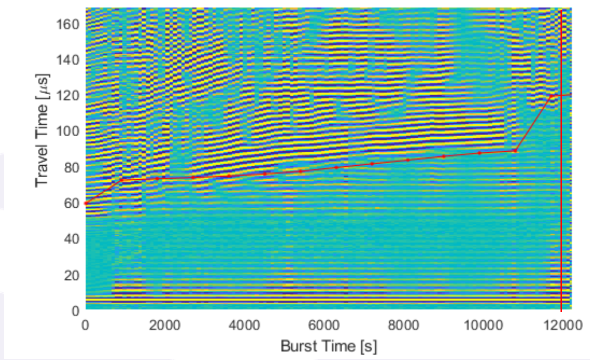




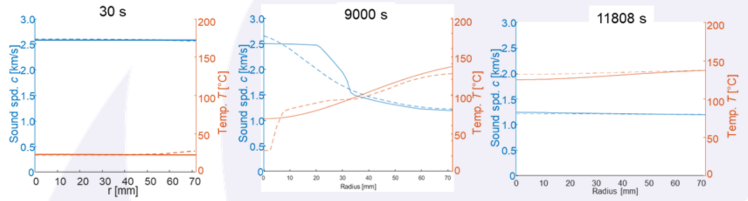
3DHEAT

Progress to date:

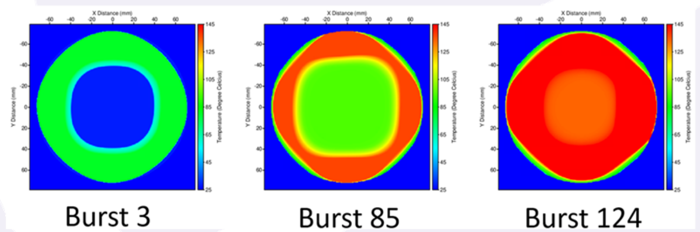
Theoretical/data processing development



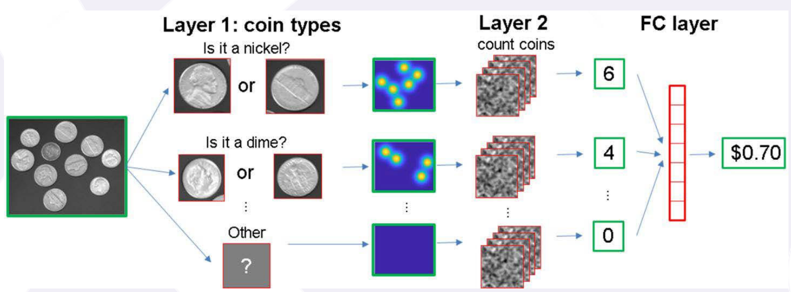
1. Pitch-catch, wave inversion



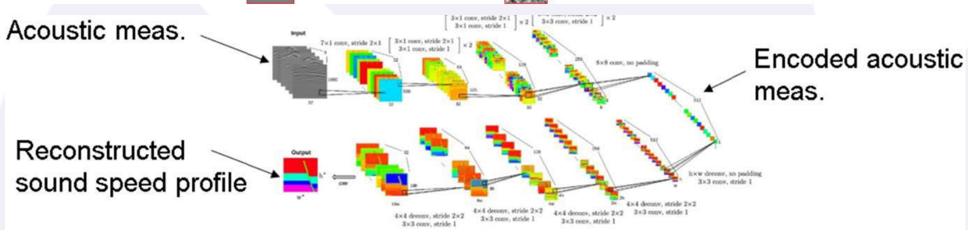
2. Least-squares reverse-time migration/full-waveform inversion



3. Machine learning, CNN (convolutional neural network)



4. Physics-based machine learning



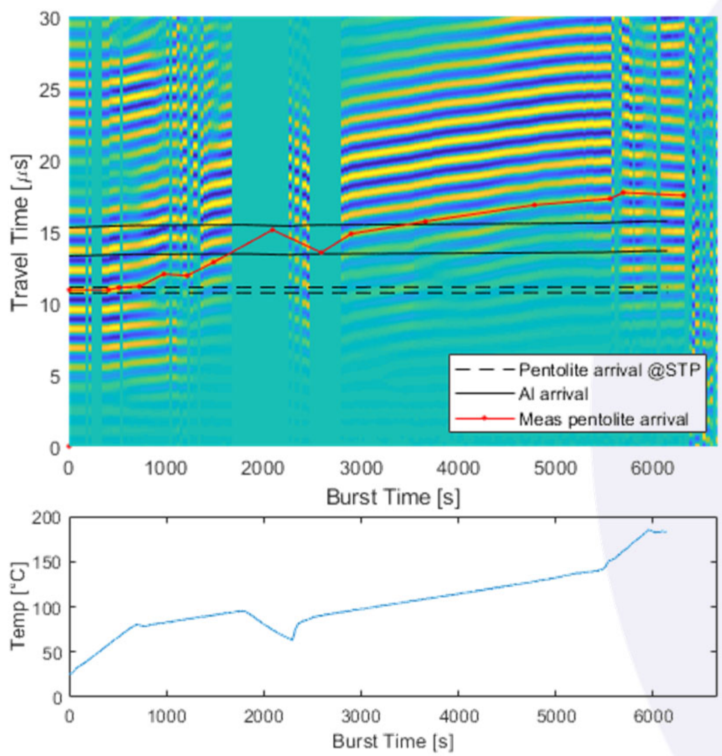
Wu et al., IEEE Trans. Comp. Imag. 6 (2018).

3DHEAT

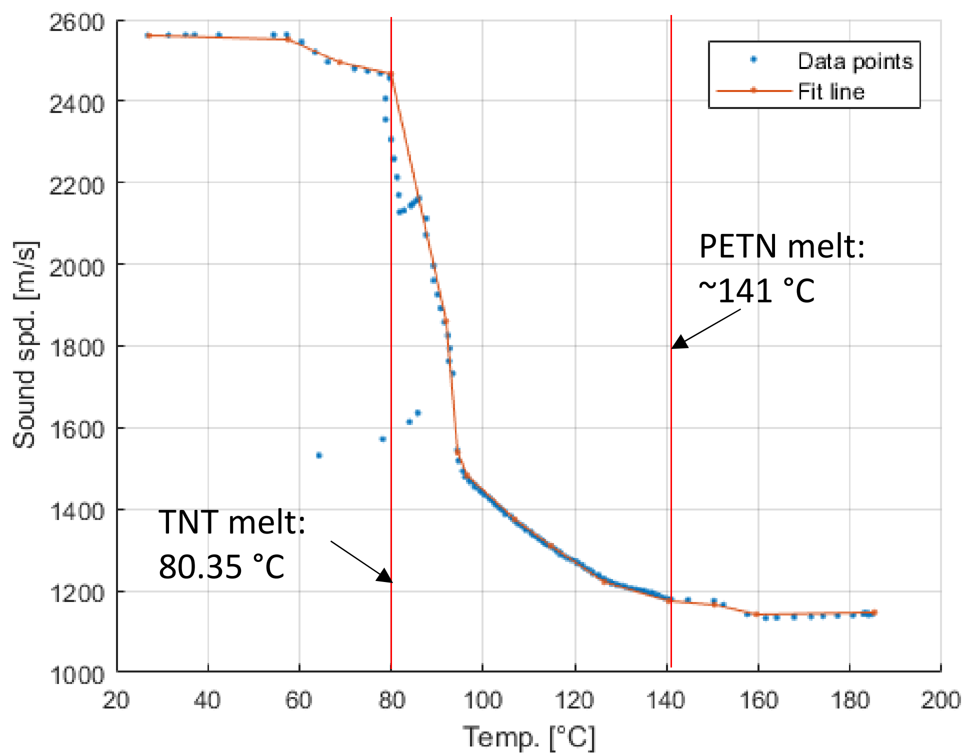
Progress to date:

Acoustics diagnosis of thermal damage in Pentolite

Experimental waveforms and temperatures



Experimental temperature vs sound speed (T-c) for Pentolite

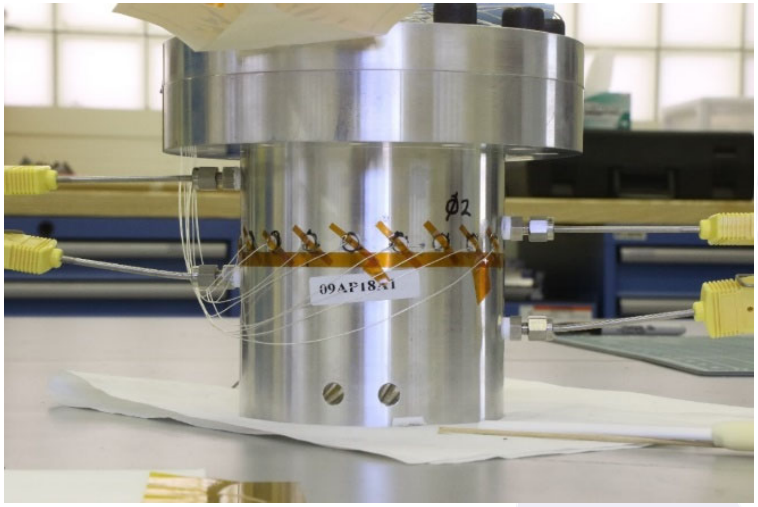


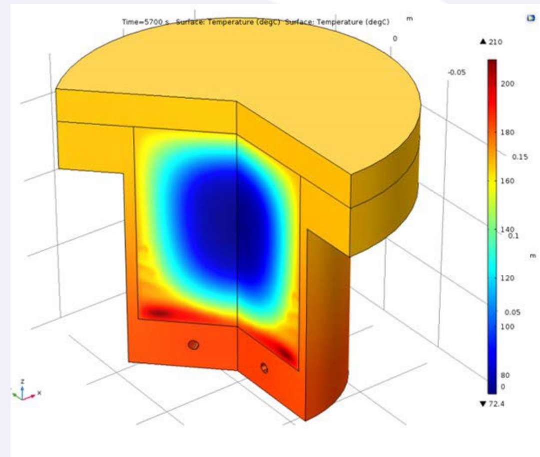
- Highest sensitivity (d*c*/d*T*) between TNT and PETN melting temps
- Spurious points due to data dropout: Verification experiment needed

3DHEAT

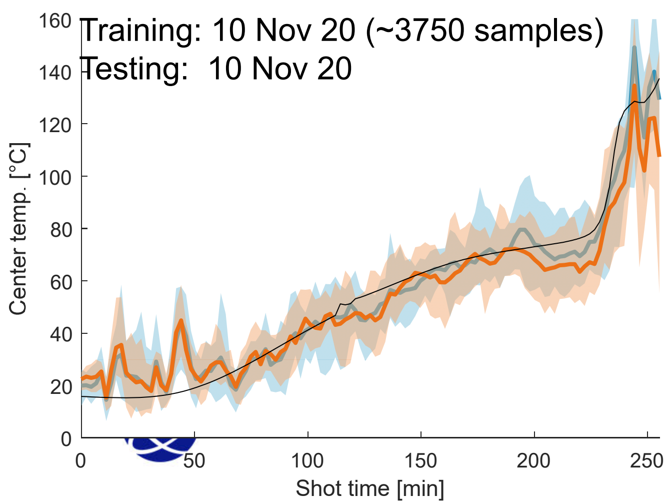
Progress to date:

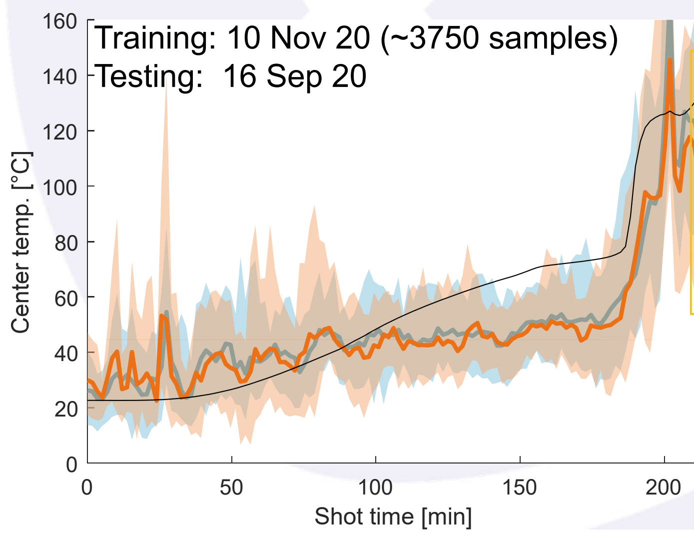
Acoustics diagnosis of thermal damage in Pentolite





Machine learning, CNN (convolutional neural network)





Low measurement error for $T_{in} < 50$ °C

Underestimates T_{in} for $T_{in} > 50$ °C

Shunt diodes added for 10 Nov 20

Additional training samples required to account for full range of experimental conditions

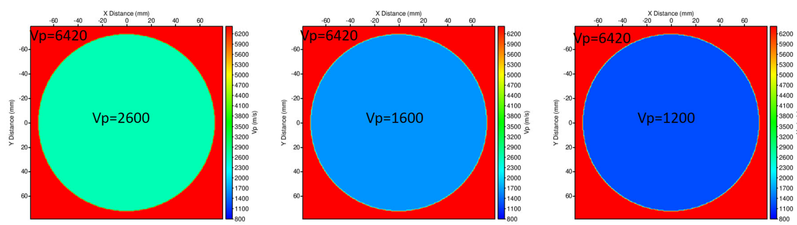
3DHEAT

Progress to date:

Acoustics diagnosis of thermal damage in Pentolite

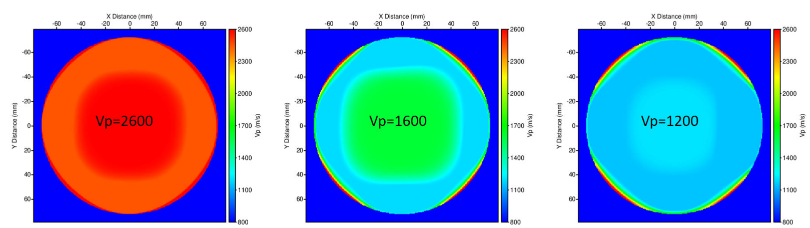
Least-squares reverse-time migration/full-waveform inversion

Initial Velocity Models



Burst 3 Burst 85 Burst 124

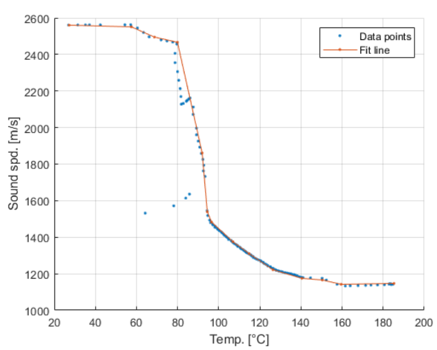
Tomography VP



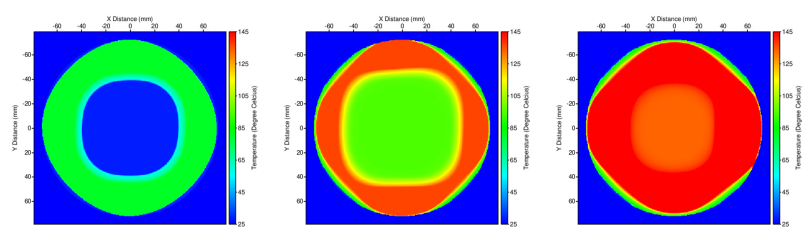
Burst 3 Burst 85 Burst 124

Steps:

- Raw data
- Front mute
- Deconvolution
- LS RTM
- Tomography



Tomography Temperature



Burst 3 Burst 85 Burst 124

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Technical challenges:

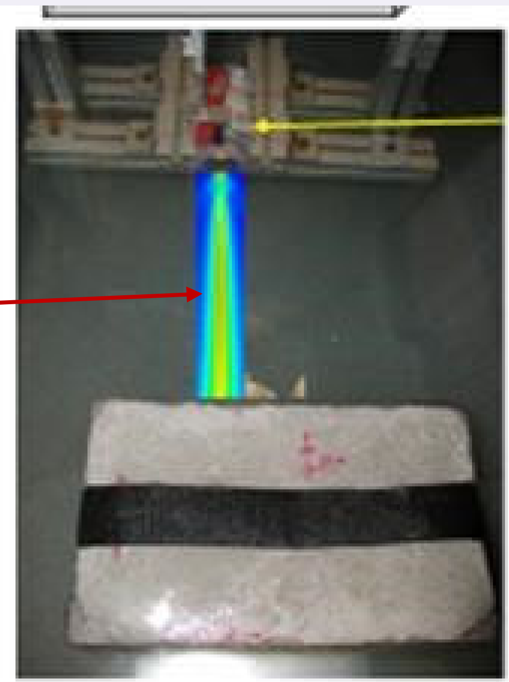
- Acoustic signal can get trapped in the casing/enclosure.
- HE is known to have significant sound attenuation, which leads to small reflections.

- These are mitigated by the unique properties of the acoustic source:

  collimation to avoid mode

  trapping, and *low frequency*

  to overcome attenuation.



Cement block in water tank

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Future work:

Task	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task A – Instrumentation development		x										
Task B – Theoretical/data processing development		x										
Project Baseline Review		x										
Task C – Build mock explosive with thermal damage												
Task D – Acoustics diagnosis of thermal damage in wax								x				
Task E – Build Pentolite cylinder block with thermal damage												
Task F – Acoustics diagnosis of thermal damage in Pentolite												x
Task G – Build mock explosive with mechanical damage												
Task H – Acoustics diagnosis of mechanical damage in wax								x				
Independent Assessment							x					
Task I – Build Pentolite cylinder block with mechanical damage												
Task J – Acoustics diagnosis of mechanical damage in Pentolite												x
Write Final Report and other Deliverables												
Final Out Brief												

Table of Milestones

Description	Tasks	Due Date
Initial instrumentation and theoretical/data processing approaches developed for HE condition determination	A, B	Y1/Q2
Demonstrate successful thermal damage detection in mock HE	C, D	Y2/Q4
Demonstrate successful mechanical damage detection in mock HE	E, F	Y2/Q4
Demonstrate successful thermal damage detection in Pentolite	G, H	Y3/Q4
Demonstrate successful mechanical damage detection in Pentolite	I, J	Y3/Q4